SyncFueL – Concept of remotely synchronized Own-Consumption for charging Electric Vehicles

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Abstract— In order to reach the goal of national governments to reduce the CO2 emission, the change from fossil mobility to electric mobility can be a mighty measure if Renewable Energy Sources (RES) are used for charging the electric vehicles (EV). A successful change needs charging infrastructure with special requirements. On the one hand charging infrastructure has to be available and on the other hand the needed energy has to be generated by RES on acceptable costs. Our study is focusing on metering and load synchronization to charge EVs with own produced energy by using the public grid (SyncFueL). We will show a technical concept for the remote synchronization between RES feed-in and EV charging power together with a metering and clearing concept to also enable the market process side. The study will motivate the importance of this research topic (for the future grid) first. Then we will give an overview of the related work. As the main part of this study the concept of remotely synchronized Own-Consumption for charging Electric Vehicles is described in detail, followed by the relevant research topics. The conclusion and outlook will summarize the findings and outline further work.

Index Terms--SyncFueL, electric vehicle, charging infrastructure, own consumption, mobile metering, virtual direct link

I. Motivation for Synchronized Own Consumption for Electric Vehicle

Electric vehicles have a potential to reduce the worldwide CO_2 emission if they are charged by RES. This requires comfortable and at the same time reliable charging and sustainable infrastructures [1]. However, the integration of EVs in a RES based energy system is a challenge. One possible answer is to expand the grid e.g. to bring wind energy from windy coast regions to regions with high EV penetration. Another opportunity is to store the surplus energy locally and use this energy for charging on demand. A further possibility is to use EVs as dynamic loads to balance local RES energy during the charging process. Local RES are often photovoltaic systems on private roofs. Balancing private and local photovoltaic feed-in in smart home infrastructures due to controlled charging of electric vehicles shows positive initial results concerning the reduction of the impact of the photovoltaic feed-in on the grid [2]. Charging an EV with own photovoltaic energy can be a very economical way because of the PV plant's low energy generation cost. The challenge of using EVs to balance local RES, especially photovoltaic, is the availability of the vehicle during the day. Usually, during the day the EV is used for activities out of home and thus out of the smart home's local energy system for the charging process. However, due to the restricted driving range, EVs are typically in a close vicinity to their user's homes. For example, EVs charge at malls, shops, supermarkets or at work in the near field area of the smart home photovoltaic feed-in. This motivates the research idea of the SyncFueL project: to use the public grid to connect RES with the EV and synchronize their feed-in and charging power. In this case, we expect a reduction of the impact from photovoltaic or EV to the grid – in particular the low voltage grid - which provides the opportunity to develop new use cases and business cases. We presume the following benefits for this use case:

- reducing the CO_2 emissions due to charging EVs by using regional energy from RES
- using EVs as flexible load in smart grids with volatile feed-in
- new financing models for charging and PV infrastructures

II. Related Work for Integration of Electic Vehicle to the Grid

To find some related work for remotely synchronized Own-Consumption for charging Electric Vehicles there are four

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points that require addressing. Besides the listed points, reducing CO_2 emission / cost and using EVs as flexible load, a discussion about new financing models and the information and communication technology is necessary.

Coordination methods based on several optimization problems are researched to outline the potential of using controlled charging to reach different or the same optimization targets. They simulate different optimization models and optimization goals [3]. Sortomme et al. [4] discussed a global optimization of minimize grid losses. Gottwalt et al. [5] uses historical renewable energy data to simulate a power system under two charging strategies. The first charging strategy uses an as fast as possible strategy while second strategy is an optimal strategy. It finds that by using the optimal strategy the total demand met by RES increases. The concept of remotely synchronized Own-Consumption for charging EV was not a subject of known research.

III. Concept of Remotely Synchonied Own-Consumption for Charging Electric Vehicle

The goal of our study is to investigate load synchronization to charge EVs with own produced energy by using the public grid. For this purpose, we develop a technical and economical concept. Figure 2 illustrates the smart home system with a RES feed-in. In times of surplus production the smart home system feeds its surplus energy into the public grid. The goal of this concept is to enable the usage of this energy to charge an own EV at a remote connection point. This connection point could be, in this concept, different possible charging infrastructures, like a wall box, a normal plug, or public charging infrastructure. Metering and ICT infrastructure enable the synchronization and the clearing of the system. As the metering device, the Smart Meter (SM) of the Smart Home will be modified to send clearing data and synchronization data. On the EV side the metering system of the charging infrastructure receives the synchronization data and sends the clearing data.

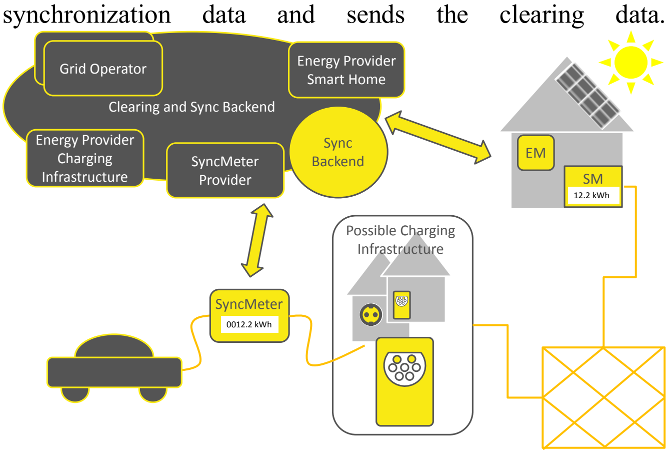

Figure 2: Technical concept of the SyncFueL approach

Because of the different functions in the harmonized electrical role model [6], the back-end systems for synchronization and clearing are split in two physical systems. The synchronization back end manages the synchronization between the charging process and the surplus energy and the clearing backend provides the billing events for the clearing house, which manages the processes between all involved market roles.

IV. Research Topics to Enable Remotely Syncronized Own Consumption

The first step to investigate the concept is to discuss different research topics. At first, the impact on the grid has to be estimated. On this basis, an economical concept has to evolve. The technical concept has to enable the defined economical concept. For this purpose, the functions of synchronization between RES feed-in and charging power will be defined and a metering and clearing concept must be created.

A. Impacts to the grid

Residential PV plants are a part of the (smart) home electric infrastructure. Thus, they feed-in the low voltage grid. The nominal power of these PV plants are limited by the roofs dimensions. So, typical nominal power is between 3 kW_{peak} and 10 kW_{peak}. Consequently, AC based charging infrastructure that fits to this power range is qualified for the SyncFueL charging concept. Typical charging points are on the one side public charging stations and on the other side private and semi-private charging points. Assuming that EVs charge in close vicinity of the home, it makes sense to analyze the active use of the grid during the SyncFueL charging concept.

For example, Figure 1 shows three different load situations. In case 1, the charging point is in the same low voltage grid as the PV plant. Therefore, the capacity of the upper grid levels is not needed for transferring the energy of the own PV plant to the own EV. Correspondingly, case 2 needs the low and medium voltage grid but not the high voltage grid. Only in case

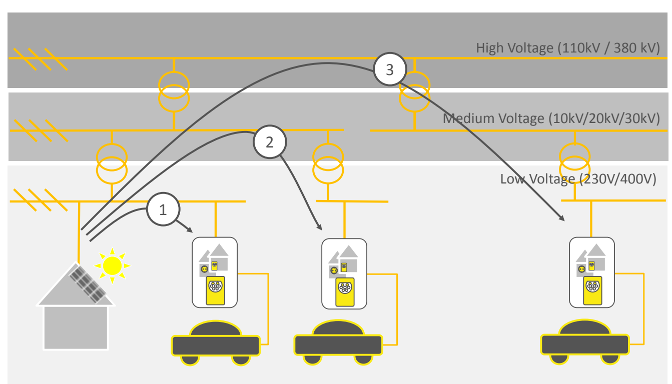

Figure 1: Overview of SyncFueL's EV interconnection setups with involvement of various grid levels

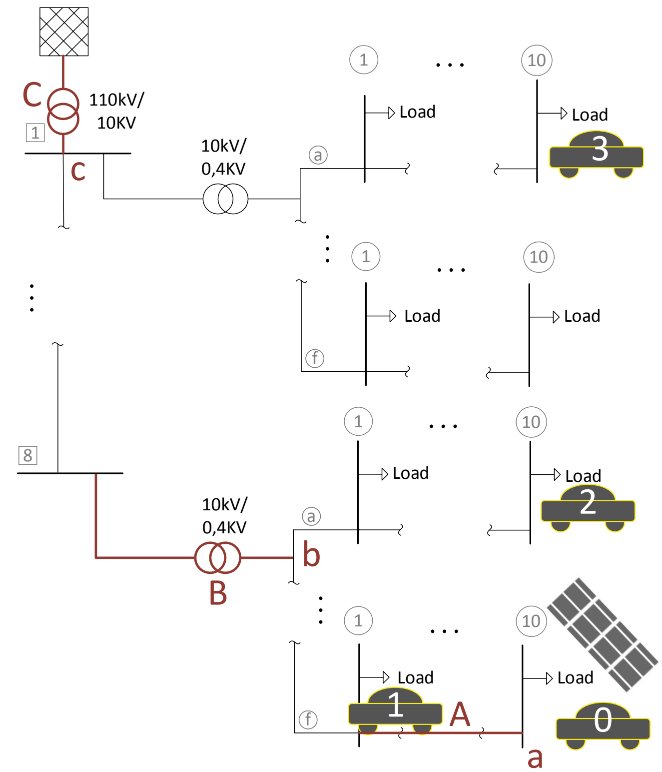

Figure 3: Simulation Grid with different charging points and points of interest

3 shall all grid levels be used. In the end, we define a ‘virtual direct link’ between the feed in point and the electric vehicle which enables the remotely synchronized own-consumption. To evaluate the impact of the virtual direct link a grid simulation based on the model in Figure 3 is performed. Here we define four possible charging positions.The first one is charging at home, without using any public grid. This is our reference case. Case 1 is at the end of the same low voltage feeder as the feed-in. Case 2 is at the end of low voltage feeder, which is connected to the same medium voltage transformer. Charging point case 3 is at the end of a low voltage feeder, which is connected to another medium voltage transformer. This transformer is at the same medium voltage feeder like the feed-in. The simulation time is one day, with a standardized load profile for the loads and PV generation. The PV power P_{PV} of the feed-in smart home has a maximum energy of 22kW and is synchronized with the charging energy P_{ch}.

$$P_{PV} = P_{ch} = 22 \text{ kW} \quad (3)$$

To see the impact to the grid we define the points of interests A, B, and C. At the connection of feed-in (A), the medium voltage transformation (B) of the smart home and the high voltage transformer, we analyze the workload. At the three connection points a, b, c we analyze the voltage. The results of the grid simulation (Table 1) show the four cases and simulations without EVs. In each of the four cases a calculation with and without a virtual direct linked photovoltaic feed-in is made. The results from these calculations are workloads of the points (A), (B) and (C) and the variance of the voltage (Delta V) from the normalized voltage level. It is shown in per cent for point (a) and in per mille for point (b) and (c). It can be seen in the first result, the photovoltaic feed-in increases the workload on the line (a), but decreases the workload on the transformers. The voltage variance, delta V, is also reduced.

By connecting an EV without any synchronized photovoltaic power, the workload and the voltage variance increases in every case and in two cases the voltage level violates the voltage constraints. By using a virtual direct link to synchronize the photovoltaic feed-in all voltage deltas reduce. The highest reduction can be seen in Case 0. In this case, the highest reduction is also by the workload on line A. In case 1, 2 and 3, there are reliefs for the transformers but no relief for line A. In summary, a virtual direct line lowers the voltage delta by the executed simulation and the connections (lines and transformers) will be relieved as the grid layers are not used by the virtual direct link.

Table 1: Workload and Voltage of the simulation results

Case	PV	Case 0	Case 1	Case 2	Case 3	A	B	C	a	b	c
	P_{PV} / kW	P_{EV} / kW	P_{EV} / kW	P_{EV} / kW	P_{EV} / kW	Workload / %	Workload / %	Workload / %	Delta V / %	Delta V / ‰	Delta V / ‰
	0	0	0	0	0	1,70	26,65	3,05	8,78	5,45	0,72
	-22	0	0	0	0	11,81	23,15	3,00	3,23	5,03	0,72
0	0	22	0	0	0	20,45	33,87	3,20	27,31	6,89	0,79
	-22	22	0	0	0	1,70	26,65	3,05	8,78	5,45	0,72
1	0	0	22	0	0	1,70	30,14	3,10	10,00	5,86	0,73
	-22	0	22	0	0	11,81	26,65	3,05	2,00	5,45	0,72
2	0	0	0	22	0	1,70	26,65	3,05	8,78	5,45	0,72
	-22	0	0	22	0	11,81	23,15	3,00	3,23	5,03	0,72
3	0	0	0	0	22	1,88	28,61	3,20	9,63	6,08	0,79
	-22	0	0	0	22	11,48	24,87	3,14	2,89	5,58	0,78

B. *ICT concept for remotely synchronized own-consumption for charging PEVs and its challenges*

As part of this work we propose an ICT architecture for metering and synchronization between a local RES (e.g. PV-, mCHP station, etc.) and a remotely located charging station or socket. The ICT architecture is responsible for synchronization of the feed-in rate of the RES and the remote feed-out rate at the charging station including the corresponding energy metering for billing purposes as shown in Figure 4. The core intention of this approach is to reduce the overall impact of local RES, particularly on the LV/MV grid as discussed in the previous section. The proposed ICT architecture faces two major challenges. Correspondingly, the ICT architecture is divided into two technical scopes with different sets of underlying requirements:

1. Metering: Secure and cost-efficient clearing and billing process for remotely synchronized own-consumption that is compliant to relevant regulations for energy

metering and billing of power distribution. Involved market roles including their relationships and interdependencies are proposed accordingly in section C.

2. Synchronization: Secure near real-time synchronization process between local feed-in power rate (RES) and remote feed-out power rate (target charging power of PEV) which remains valid for various RES topologies and PEV charging scenarios as well as aggregation levels.

In case of scope 1 (metering), relevant metering standards like IEC 62056 series (DLMS/COSEM) as well as the "Protection Profile for the Gateway of a Smart Metering System" (SMGW-PP) [7] need to be considered for non-repudiation of locally provided and remotely consumed energy. The energy supplier needs to provide additional energy, in case the locally fed-in energy of the RES is not enough for charging the PEV and vice versa. This aspect needs to be considered by the underlying metering process in the *Smart Metering Service* of Figure 4 in order to ensure a correct billing process.

In case of scope 2 (synchronization), it is also necessary to meter and observe the feed-in rate over time of the RES, e.g. again with IEC 62056. However, in addition to observing the feed-in rate, a synchronized control mechanism for the feed-out rate is necessary. In this regard, protocols like OpenADR [8], IEC 61850 (for DERs) [9] or the Smart Energy Profile 2.0 need to be evaluated and mapped to the proposed synchronized RES feed-in and PEV charging process. Depending on the underlying charging infrastructure, other protocols like OCPP [10], IEC 61850-90-8 [11] or vendor-specific ones may also be relevant candidates for control of dedicated charging equipment.

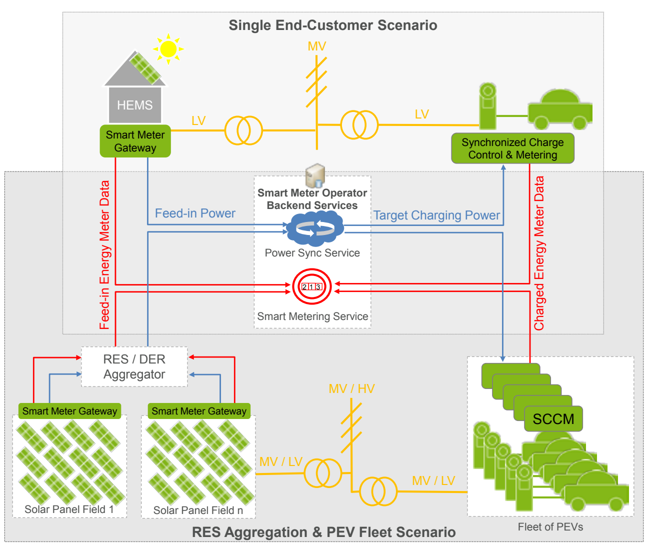

Figure 5: ICT Concept for remotely synchronized Own-Consumption for Single and Fleet PEV Charging Scenarios

In addition to the communication and protocol related challenges, the control and synchronization mechanisms need further evaluation. On the feed-in side, the Home or Facility Energy Management System (HEMS, FEMS) controls the internal and external energy flow. It controls what amount of power is fed into the grid for remote consumption by the PEV vs. what amount of power is consumed locally by other loads deployed in the home or facility. A corresponding algorithm in the HEMS / FEMS needs to balance between these two contradicting requirements based on some optimization criteria (e.g. cost).

The *Power Sync Service* as depicted in Figure 4 is responsible for synchronizing the feed-in rate of the HEMS / FEMS with the PEV charging process(es) reliably. In the *Single End-Customer Scenario* as depicted in Figure 4, this synchronization is rather straight forward, due to its one-to-one correspondence. However, in case of the *RES Aggregation and PEV Fleet Scenario,* as shown at the bottom of Figure 4, the available power that is fed-in by RES needs to be synchronized and distributed over a complete fleet of PEVs. This synchronization involves an optimization problem bound to the number of PEVs in the fleet as well as to their individual characteristics and requirements (e.g. battery capacity, state of charge, estimated departure time, etc.).

A SyncMeter (Synchronized Charge Control & Metering, SCCM) at the charging site, as depicted in Figure 5, is responsible for providing all charge process related information to the *Smart Meter Service* as well as the *Power Sync Service*. The SCCM shall be able to connect to varying types of charging points, ranging from private to public infrastructures. Hence, depending on the kind and sophistication of the underlying charging infrastructure, a SCCM may be incorporated in the supply equipment (charge spot), an in-cable control box, or may be even deployed inside the PEV. In the last case, SCCM implements the respective standards to communicate with a dedicated PEV only. In case the SCCM is not deployed inside the PEV, relevant standards series like IEC 62196 [12],

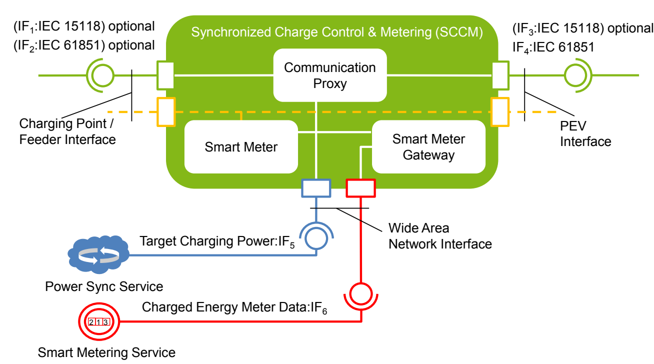

Figure 4: Concept overview of the Synchronized Charge Control & Metering (SCCM)

IEC 61851 [13] and ISO 15118 [14] need to be taken into consideration in order to ensure sustainability of the approach and long-term interoperability with different and future types of PEVs. Furthermore a user interface is necessary (e.g. Smart Phone) to request target requirements of the charging process by the user and to display relevant data.

C. Market roles and Clearing Concept for SyncFueL

A comprehensive metering and clearing concept will enable the SyncFueL concept. Besides this, the market model has to be analyzed. To shed some light on it, we will show an example of the German energy market. Equation (1) shows the formula of the energy cost for a private customer (in Germany) as the summary of production $€_{kWh,\ prod,\ mix}$, taxation $€_{kWh,\ tax}$ and EEG reallocation charge $€_{kWh,\ EEG}$, concession $€_{kWh,\ concession}$ and transferring $€_{kWh,\ trans}$ cost. In case of a fair distribution of the costs they reduced to the own PV generation costs plus the translation costs. The transition costs are the sum of low voltage $€_{kWh,\ LV}$, medium voltage $€_{kWh,\ MV}$ and high voltage grid $€_{kWh,\ HV}$ costs. Consequently, the energy cost reduced by the $€_{kWh,\ HV}$ in case 2 and raised by $€_{kWh,\ MV}$ in case 1.

$$€_{kWh,\ gird} = €_{kWh,\ prod.mix} + €_{kWh,\ tax} + €_{kWh,\ EEG} \quad (1)$$

$$€_{kWh,\ concession} + €_{kWh,\ trans}$$

$$€_{kWh,\ sync} = (€_{kWh,\ PV} +)\ \ €_{kWh,\ concession} + €_{kWh,\ trans} \quad (2)$$

$$€_{kWh,\ trans} = €_{kWh,\ LV} + €_{kWh,\ MV} + €_{kWh,\ HV} \quad (3)$$

To use the public grid a metering and clearing system is necessary. Every feed-in and load connection needs an energy meter as a kind of clearing measure to the grid. Therefore, we develop a special metering concept that deals with two metering points: One on the home side and one on the EV side. In the shown concept a smart meter (SM) measures the feed-in energy and the load meter is a part of the SyncMeter. A special requirement is, not only to meter the energy. To get the information about the balanced energy we need a time based energy metering or a power meter. A grid simulation including load profiles from the EVs and PV plants will deduce the precise specification. A backend system evaluates the synchronized energy from the metered power and energy data. Therefore, the backend aggregates the metered data from the meter operators of the energy providers of the smart home and the SyncMeter.

The backend system has also the function of clearing between all involved operators. The clearing system balances the charged energy with the energy provider of the smart home. If there are other providers (e.g. charging infrastructure) a clearing is needed for them, too. Another job of the clearing system is to analyze the involved grid operators and account the grid fees to them.

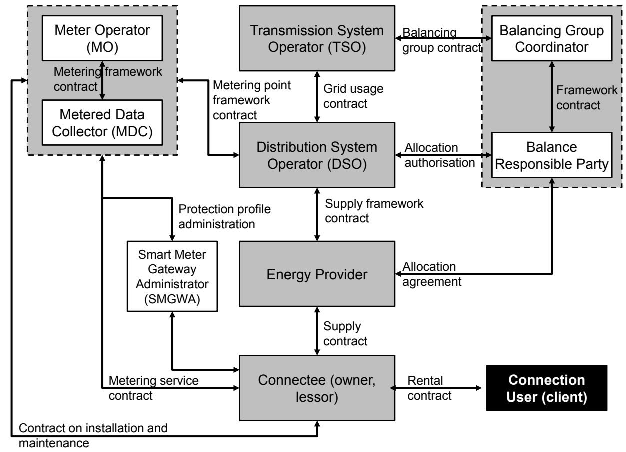

Figure 6: Market Roles based on the harmonized electricity market role model of the ENSO-E

To integrate a concept of remotely synchronized own-Consumption for charging electric vehicles into the energy system one must know the market roles and contractual relations. Figure 4 gives an overview of the current market roles based on the harmonized electricity market role model of the ENSO-E [6]. The model also shows the market role of the Smart Meter Gateway Administrator (SMGWA) although the contractual classification is still in abeyance due to specific regulations are still pending.

We suggest that there should be the role of a provider for the SyncMeter that partly fulfills tasks and processes of the involved market partners within a business process outsourcing (BPO). This could be part of the currently discussed new market role of a Smart Meter Operator (SMO) as a further development of the Meter Operator (MO). The SMO, like the MO, has an interface with all relevant market partners and especially with the SMGWA. At the same time the SMO has all the necessary contract relations to all the relevant partners in advance. This constellation permits the SMO's access to all the relevant data and partners for providing and accounting new services like a SyncMeter.

V. CONLUSION AND OUTLOOK

This paper represents a study on a concept for remotely synchronized own consumption for charging electric vehicles. We first motivated the issue then we described and illustrated the concept. This study includes an in-depth state of the art analysis of remote synchronization of EV charging power and PV metering concepts. Especially the topics controlled charging, communication and market models for electric vehicle are relevant. Then we derived the research topics to enable remotely synchronized own consumption. Topics include HEMS, charging infrastructures, charging control strategies and appropriate standardization measures, and clearing concepts focusing on the energy market and remote synchronization.

As main results, we presented in detail a grid simulation to outline the impact of SyncFueL to the grid on the one site. Therefore, the concept of a virtual direct line is worked out first. Based on this concept a basic simulation shows the impacts of the virtual direct line. The main impacts are a lower voltage drop, bred by the charging of EVs. The workload of the connections (lines and transformers) will also be relieved as the grid layers are not used by the virtual direct link.

We furthermore presented a novel ICT concept for remotely synchronized own-consumption for various PEV charging scenarios. This concept is divided into dedicated metering and synchronization scopes in order to cope with various potential market models and to align as close as possible with today's real world applications and state of the art in standardization. A detailed analysis on relevant standards for both scopes is presented. The exact mapping to these candidates needs to be determined in future work. The underlying communication technology also needs to be considered in more detail. Due to very scarce amounts of data being transmitted over time, the impact of different data rates of different communication technologies is expected to be quite limited. Scalability and robustness on the other hand will need to be considered in more detail. An appropriate market model with all relevant parameters and a detailed metering concept is also required.

Future topics include algorithms for the HEMS and the control strategies for charging the EV. This should contain for example grid constrains to prevent critical load situations. More detailed grid simulations with a higher penetration of remotely synchronized Own-Consumption and virtual direct links are other topic for future work.

Acknowledgment

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